# Non-photorealistic Rendering on Mobile Devices and its Usability Concerns

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**Abstract:**

The increasing amount of geographic data in urban environments and the technological advances in the domain of mobile devices have stimulated cartographers to give a try with the 3D visualisation of urban information on small mobile displays. The paper is focused on one of the fundamental research questions: How can we design a mobile 3D virtual urban environment that allows its users a cognitive adequate information processing? The prevailing photorealistic visualisation techniques reveal some drawbacks with regard to mobile usage context. We believe that the non-photorealistic rendering (NPR) approach with its capability to unite the advantages of photorealistic presentation style and abstract 2D maps can better satisfy the design constraints for mobile applications. Starting from an outline of the development trends of virtual urban environments, we give an overview of 3D NPR techniques along with their potential of 3D information communication to mobile users. Based on a general analysis of usability issues, we propose "cognitive adequacy" as the usability measure for NPR approach. A set of applicable graphic variables and design options are presented as our first results. In the further stages of our work, two extensive virtual urban environments with NPR approach will be implemented in accordance with the OGC format CityGML and undergo usability tests.

## 1. INTRODUCTION

The rapid development of photogrammetric and remote sensing technologies has led to the increasing availability of highly detailed 3D digital city models that typically consist of buildings with roof and façade elements, trees with various branch types, step structures that connect buildings with terrain forms, streets with associated navigation facilities etc. (Meng et al. 2007). Being draped with simulated textures or photos from the real world, such a city model would give an immersive photorealistic impression if it is suitably rendered on a graphic display medium. Due to its ability of allowing an intuitive perception of spatial relations, 3D photorealistic visualisation has been prevailing in desktop mapping system since nearly two decades. Its graphic quality has been progressively improved according to the motto "making things truer than the truth". To coin a photorealistic city model on miniaturised displays like smart phones and PDAs is therefore a very natural result of technical evolution. However, the designer faces two research challenges: How far is it possible to transmit and render the detailed geometries in real-time on a mobile device which has limited storage and computing capacity? Is a photorealistic duplicate the optimal way of communicating 3D urban information? While the first question strongly depends on technical progresses in terms of data structure, rendering algorithms, hardware properties and wireless communication bandwidth. The second one, the focus of our approach, is both a technical and a human issue because the user is involved as an inseparable part of the usability engineering task. General principles of usability engineering were described in (Nielsen 1993) and (Shneiderman and Plaisant 2005). Based on ISO-standards, Hermann and Peissner (2003) specialised a usability approach for 3D virtual urban environments.

Shneiderman (2003) stated that 'Some designers dream about building interfaces that approach the richness of 3D reality. They believe that the closer an interface resembles the real world, the easier the usage. They strive for resolution that matches film—with rapid camera movement and lively animated objects. This is a dubious proposition since user studies show that disorienting navigation, complex user actions, and annoying occlusions can slow performance in the real world as well as 3D interfaces. (p. 12)". MacEachren and Kraak (2001) assumed that the 'approaches to desktop interface design will probably not work when used with … immersive Virtual Environments or on small mobile PDAs …' (p. 5). They pointed out the two basic constraints of graphic design for mobile devices: limited display space and limited interactivity. Users in a mobile environment are constantly influenced by external visual, auditive and haptic stimuli beyond the mobile display (Reichenbacher and Swienty 2006). These stimuli may, on the one hand, distract and hinder the attentional performance, e.g. by deviating gazes from the display, but on the other hand, they may also contribute to the overall information acquistion and understanding. The inherently strong interaction between the virtual and the real world requires a smooth switch from one to another, hence, the immediate usability of the virtual environment. With this regard, a photorealistic 3D city model suffers three drawbacks:

(1) A photorealistic city model with typically unclassified geometric details reveals a low abstraction level. The user faces a high cognitive workload of information processing (Bunch, Lloyd 2006). He has to rely very much on his cognitive skill of visual attention, i.e. the ability of sifting through the rather crowded graphic in order to notice the relevant information for his application such as pedestrian navigation.

(2) Due to the limited interactivity and reduced vision field, the recognition of depth cues embedded in a photorealistic city model is less straightforward and cognitively more demanding on small displays than on desktop PC.

(3) Users' attention may be entirely locked on the appearance so that less effort will be made to look for the information behind the surface. In addition, users may be likely confused by the details that are not up-to-date.

Keeping these considerations in mind, we adopt the 3D non-photorealistic rendering (NPR) approach with the objective to create various visualization alternatives that possess the following useful characteristics:

(1) They have a reduced visual complexity as compared with photorealistic visualisation, but still they give a naturalistic impression of the underlying city model, thus allow an intuitive and fast identification of the individual urban objects.

(2) They reveal a higher abstraction level and allow the accommodation of more semantic information than a photorealistic visualisation would do.

(3) By means of simplification, exaggeration or any other artistic treatments of 3D objects they stimulate users' attention and curiosity of querying for further information either from the underlying database or from the mobile environment.

NPR represents a new genre in 3D computer graphics. It addresses illustrative, expressive and artistic computer graphic techniques (Strothotte and Schlechtweg 2002). Various possible graphic variables and their combinations can be used as metaphors to highlight geometric and semantic characteristics of 3D objects.

## 2. 3D NPR TECHNIQUES

Among the typical NPR techniques used in 3D computer graphics are 'Cartoon Rendering', 'Sketchy Rendering' and 'Artistic Rendering' (Gooch and Gooch 2001). Similar to photorealistic techniques, they are realised through computer graphic hardware along the rendering pipeline. As shown in Figure 1, a rendering pipeline consists of basic steps of transforming a 3D data set (e.g. geometric elements of an urban environment) into a 3D model, then projecting the model onto a 2D display surface along with the necessary depth cues so that the user perceives a 3D sensation. To achieve this goal, a geometric transformation model, an illumination model and a shading model are implemented into the graphic board. Unlike the photorealistic rendering that strives for the unique "truth", these three models can be manipulated in various ways so as to give the user different illustrative 3D impressions. A first promising approach for the usage of NPR techniques to visualise 3D city models was demonstrated by Döllner and Walther (2003). An example is given in Figure 2.

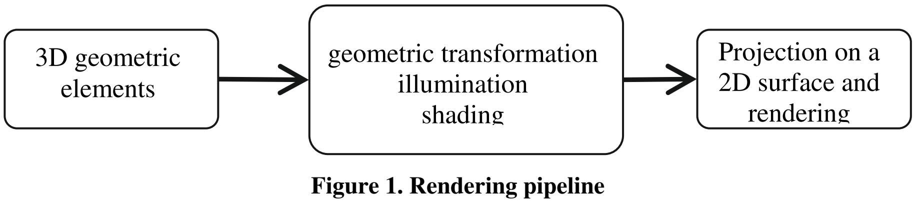


**Figure 1. Rendering pipeline**

**Figure 2. Non-photorealistic visualisation of a 3D city model of Potsdam (Döllner and Walther 2003)**

Existing NPR techniques have been almost exclusively developed for desktop computers which have much higher computing capabilities and graphic resolutions than small display devices. Adapting these techniques to mobile devices and usage context is therefore by no means a simple transplantation task. Since there is still too little knowledge about how users get along with complex virtual environments (brain processes) and what kind of impact user strategies would have on the design (Slocum et. al. 2001), we take a first step to identifying, adapting or developing graphic variables that are feasible for NPR of 3D virtual urban environments on mobile displays.

Our approach adopts CityGML which is a OGC standard file format of 3D city models. Being based on the Extensible Markup Language (XML), CityGML is implemented as an application schema for the Geography Markup Language (GML). With CityGML, it is possible to process graphical and geometrical models as well as topological and semantic information for 3D applications. The 3D visualisation software LandXplorer which can process the CityGML file format is used as our experimentation platform (Döllner et al. 2003).

## 3. FROM 2D MAPS TO 3D NON-PHOTOREALISTIC GRAPHIC

Traditionally, 2D maps serve as highly abstract scientific documents which are made possible by precise map projection, symbolisation and generalisation. Map symbols in the legend usually represent object classes. The individuality of a particular object is only implicitly indicated by its symbol bound to a particular location and its name. If for example a city with a population between 50,000 and 100,000 is represented by a circle symbol of a certain size, this symbol could remain up-to-date for a rather long time as long as the population does not grow or shrink beyond the class boundaries. For this reason, the abstraction ability of 2D maps also proportionally reflects their cost-benefit efficiency in terms of both production and maintenance expense. On the other hand, however, abstraction makes the map use a cognitively effortful task that needs intensive training. With the democratisation of mapmaking, the widespread of Internet maps and the changed map use behaviour, the traditional look of 2D maps has long been extended to include other design styles with similar cost-benefit efficiency. City plans, e.g. can have both classified abstract symbols and highly individualised landmarks. Figure 3 briefly illustrates a continuum of symbolisation from abstraction to self-explaining realism.

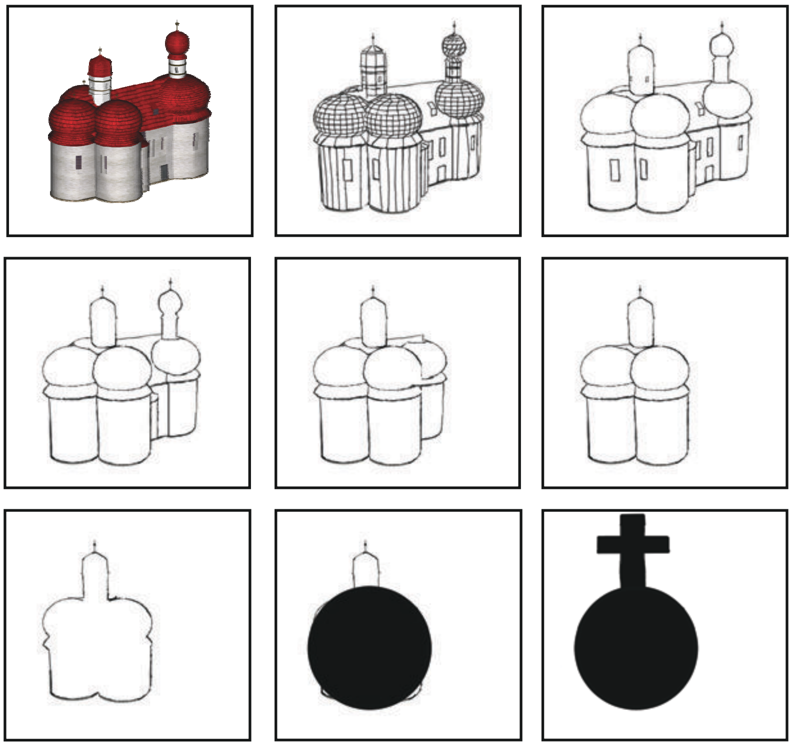

**Figure 3. From abstract to self-explaining symbolisation**

Today, many visualisation tools allow an easy combination of a 2D plan with air photos or satellite images. The resulted image map gives its user a more or less immersive impression of seamless coverage of the mapped region. However, it leaves little space to accommodate additional thematic information such as population density in urban environments. 3D city models are comparable with image maps because they also aim at resembling the environment, e.g. with orthophotos projected on roof and façade. 3D city models have gained a growing popularity among decision makers and normal citizens during recent years, especially since the GoogleEarth revolution in 2006. However, due to insufficient semantic information, the majority of existing 3D city models could only be used as photorealistic show pieces instead of urban information system. With the rapid development of geoinformation technologies and web 2.0 as a global platform for sharing collective intelligence (O'Reilly 2005), it is now increasingly possible to integrate more and more semantic information with the geometric details. Correspondingly, there is an increasing demand on the visualisation of the information-rich virtual urban environments, which should serve as a driving force to the development of the so-called informed society. The approach of 3D photorealistic visualisation will be doubtlessly further elaborated together with high-end computer graphic technologies. With regard to the diversified applications of 3D urban information, the expanding range of display sizes as well as the growing awareness of usability issues, the potential of NPR approach on mobile devices has also gained an increasing attention in the research community (Plesa & Cartwright 2008). As a whole, we could state that it has been a technical evolution from 2D map to non-photorealistic graphic (Figure 4).

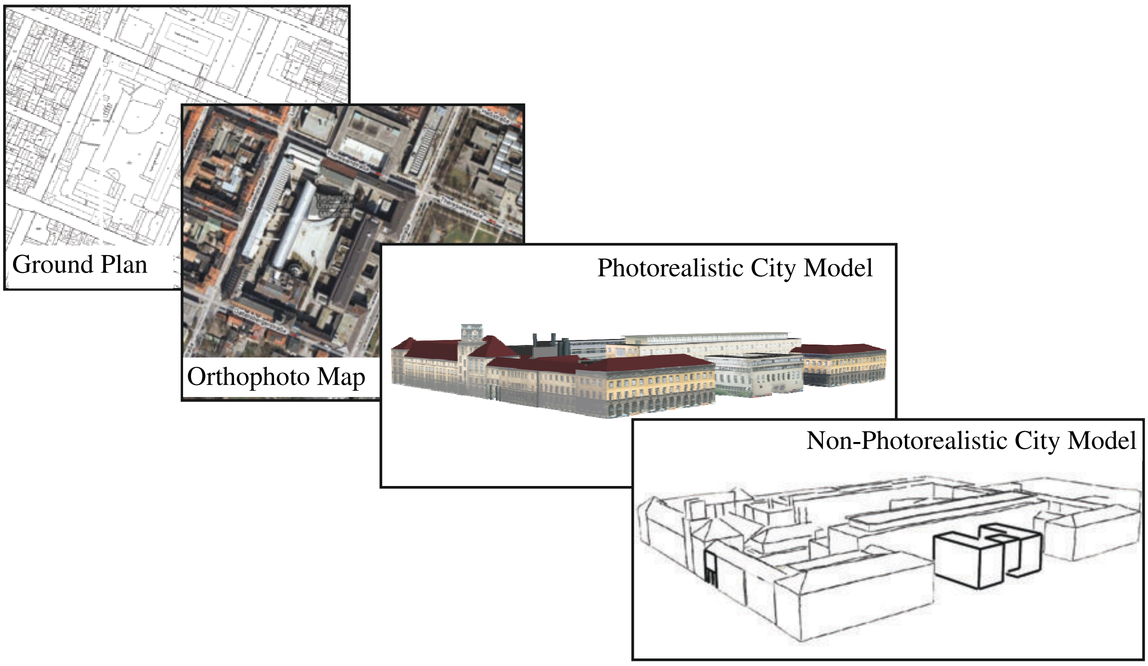


**Figure 4. From 2D abstract graphics to 3D non-photorealistic graphics**

# 4. VIRTUAL URBAN ENVIRONMENTS ON MOBILE DEVICES

## *4.1 Design Alternatives*

Depending on the adopted symbolisation style, 3D virtual urban environments can be realised in various ways, ranging from schematic topogramms to immersive photorealism. Schematic topogramms are favourable for providing overviews of urban areas which are characterised by street networks and locations of Points of Interest (PoIs). However, they are less efficient for mobile users to explore the local environments around their current positions due to too large geometric distortions in the graphics. 2D city maps are favourable for visualising ground plans, geographic objects, and corresponding semantic information. But again the large visual discrepancy between the map and the reality does not allow an immediate understanding of the mobile environments. 3D photorealistic city models allow users a straightforward interpretation of the geographic space, but their inherently high graphic complexity makes them less suitable for mobile applications due to the drawbacks mentioned in section 1. The NPR approach has the potential to unite the advantages of the above design styles and avoid their disadvantages. Since it does not have to duplicate the reality, there is a plenty of design freedom left to the developers. It allows not only the reduction of overall graphic complexity, but also a demand-driven visual highlighting of certain depth cues or important objects. Technically, non photorealistic city models require less frequent updates than photorealistic city models. In a first user test of NPR approach, Plesa and Cartwright (2008) confirmed that non-photorealistic city models are generally better accepted and understood by users due to their clarity, legibility and aesthetic appeal (Figure 5).

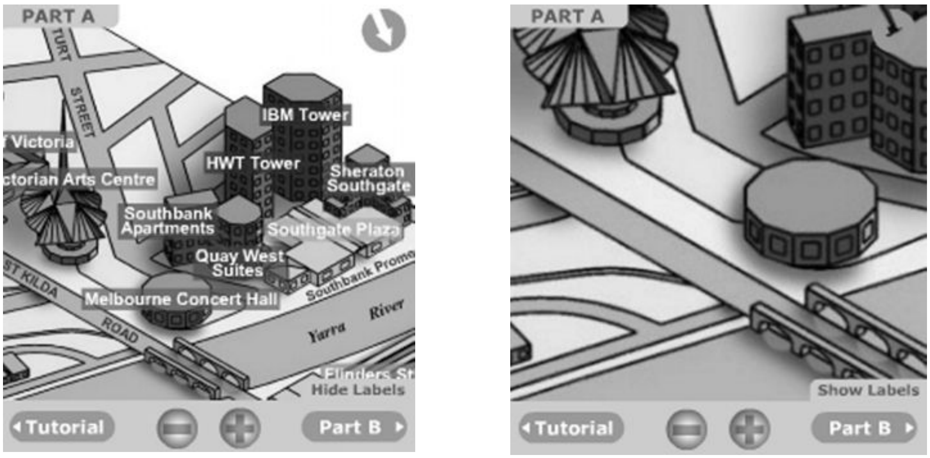


**Figure 5. The NPR prototype developed by Plesa and Cartwright (2008) (left) and an enlarged part (right)**

However, whether a NPR approach will be finally accepted or not relies also heavily on the art of design. Since there may be multiple technically equivalent NPR design solutions for the same task and target user, the confirmed usability of one NPR solution may not hold for other solutions. In order to gain an insight into the potential and general usability of NPR approach, we need to take a closer look at the cognitive capacities of mobile users and their expectations from a non-photorealistic virtual urban environment.

### *4.2 Cognition-Based Design Constraints*

According to (MacEachren and Kraak 1997), the usage of a geovisualisation system can be divided into data exploration, analysis, synthesis and presentation. Visualisation on mobile devices is mainly intended for the communication of known geographic information to a private person. Reichenbacher (2004) mentioned that orientation, localisation, navigation, search, identification and event check are the elementary user tasks in a mobile environment. While the majority of existing mobile map services has been developed to support the mobility-relevant tasks such as orientation, localisation and navigation, future development will have to meet the growing user need of getting informed of the happenings from the information-rich urban environments through the mobile devices. Accordingly, the mobile services should not only support the mobility, but also facilitate the information communication including search, query, identification and event check. The following cognition-based design constraints and associated research questions are involved in the development of NPR:

(1) *Information package*. How to package the large amount of information into spatially separable units that can be easily attended and interpreted? To answer this question there is a need to investigate the working memory of mobile users. The “golden” rule of 7 ± 2 information units that fits the memory capacity for stationary perception environment needs to be adapted to mobile context.

(2) *Interaction between the virtual environment and the real world*. What is the desired degree of attention to the small display size (6x8 cm) of mobile devices? The mobile user typically has his primary interaction with the real world, while taking the mobile device as a supporting tool. Therefore, the visualisation should not draw too much visual attention of the users. Instead, it should allow immediate identification or re-visit of relevant information and facilitate an easy remembering on the other hand.

(3) *3D sensation*. How to preserve the 3D sensation in the simplified graphics? Since the 3D sensation positively influences the emotional state of users, it helps to enhance the efficiency of orientation and navigation. There is a need to strike a balance between reduction of graphic complexity (information hiding) and exaggeration of important objects or landmarks (information highlighting).

# 5. USABILITY CONCERNS

## *5.1 Usability Measure*

According to Nielsen (1993), the usefulness of a system is reflected by two fundamental aspects – utility and usability (Figure 6). While utility describes the fitness of a system for a certain task which can be relatively easily quantified, the usability defines how well users are supported by the system during task performance. It is difficult, if not impossible, to quantify the usability because it has to do with human-related parameters - learnabillity, efficiency, memorability, error rate and degree of satisfaction.

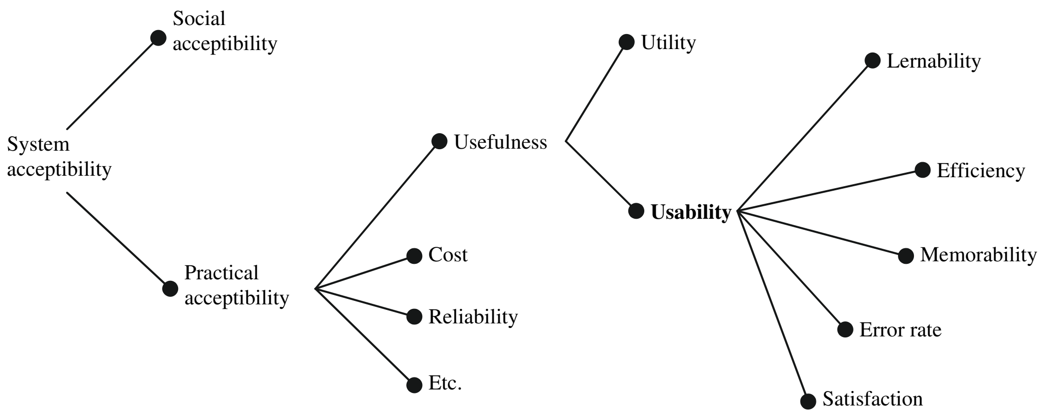


**Figure 6. Attributes of the system acceptability (Nielsen 1993)**

Currently available visualisation services on mobile devices have been mainly focused on the technical feasibility. Although more and more general ergonomic characteristics are being considered during the design (Hermann and Peissner 2003), the mobile user remains an unknown or imprecise parameter. Consequently, there is a mismatch between what the visualisation service offers and what an average mobile user can quickly get or between what is technically possible and what makes sense from user's perspective. During visual information processing, users make use of existing knowledge or information from the mobile environment to get an idea of *what* they are searching for (top-down strategy). Additionally, the sensory input from a cognitive adequate NPR solution will guide users to attentively know *where* relevant information is located (bottom-up). The interaction of bottom-up and top-down processes controls *where*, *how*, and to *what* users pay attention to (Corbetta, Shulman 2002), hence the selective information acquisition. Being aware of the iterative information process and the existing mismatch, we define *cognitive adequacy* as a usability measure for NPR solutions on mobile devices. Concretely, cognitive adequacy can be expressed as a weighted mean from four submeasures (1) the relative speed at which user's visual attention (gaze movements) is directed or re-directed to objects of interest, (2) the degree of visual concentration on the objects of interest (gaze fixations), (3) the degree of easy remembering of perceived objects of interest, and (4) task-driven cognitive efficiency such as the relative speed at which the objects on the display are matched with their counterparts in the real world (identification), or the relative speed at which certain information is interactively acquired (event-check). The first three submeasures reflect the capability of NPR solutions to guide users' attention to the relevant information and remember it, the fourth one emphasise the impact of the mobile task on users' selection of information. Among many technically equivalent NPR solutions, the one with the highest cognitive adequacy will be regarded as the optimal solution from the usability perspective.

## *5.2 Graphic Variables*

In pre-computer era, graphic design was realised by a taxonomy that essentially consists of six graphic variables "shape", "size", "orientation", "colour hue", "value", "spacing" and "texture" and their combinations (Bertin 1967). The development of multimedia technologies during last decades has substantially extended this taxonomy to include not only the further graphic variables such as colour saturation, sharpness, resolution and transparency, but also autitive and haptic variables (Mackinlay 1986; DiBiase et al.1992; Krygier 1994; MacEachren 1995; Buziek 2001). Figure 7 illustrates a set of graphic variables that are applicable for 3D non-photorealistic design. Due to lack of a systematic study on the visual effects of the new variables, however, the developers have to rely on their personal experiences and preferences in the design practice. Sometimes, the improper use or abuse of graphic variables may cause the stimulus saturation for the perception (Buziek 2001).

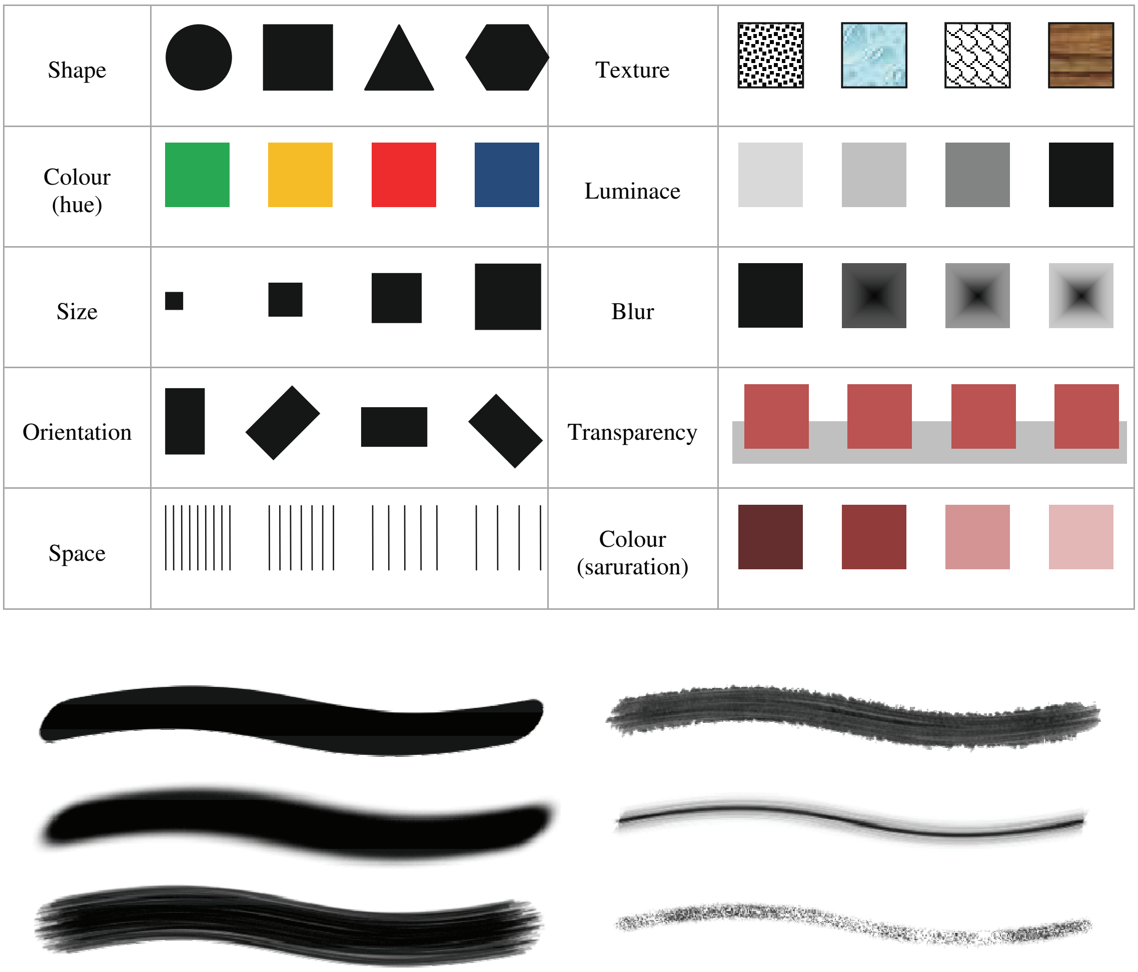


**Figure 7. Applicable graphic variables for 3D non-photorealistic design**

The 3D NPR approach for mobile devices needs to consider several constraints in selecting the suitable graphic variables and their combination. First, the design freedom is confined by the 3D structure of urban objects. That is, the graphic variables have to be bound to basic geometric elements - faces, edges or nodes of 3D objects (see Figure 8). Second, due to the perspective distortion, some graphic variables may cause perceptual confusion among users. For example, a constantly spaced surface polygon may be interpreted as variably spaced in a 3D visualisation. Third, the unpredictable illumination conditions in mobile environment may restrict or even prohibit the use of certain colour hues. On the other hand, graphic variables such as shadow, shading, occlusion and figure-ground contrast can be flexibly combined to emphasise depth cues or eye catchers in a 3D virtual environment (Meng 2003).

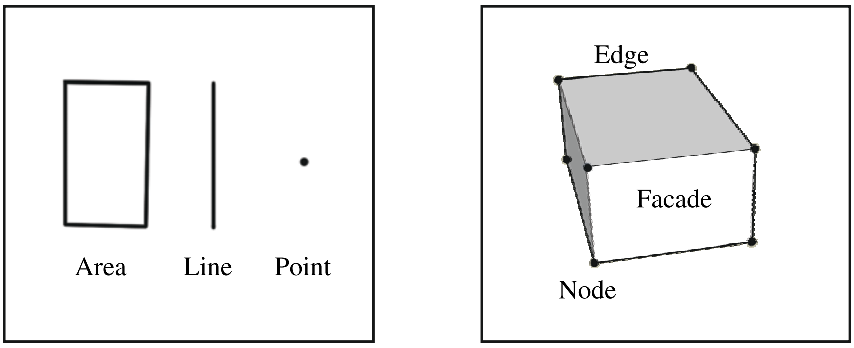


**Figure 8. Basic geometric elements of 3D objects**

According to our first investigations, “value” can be applicable to all three geometric elements. “Size” could be embedded in edges or nodes to highlight important information or enhance depth cues. “Sharpness” or “blur” could help to emphasise the distinction between important and less important object (Kosara, Mikisch, Hauser 2002). Figure 9 shows a number of NPR alternatives based on the combination of applicable graphic variables.

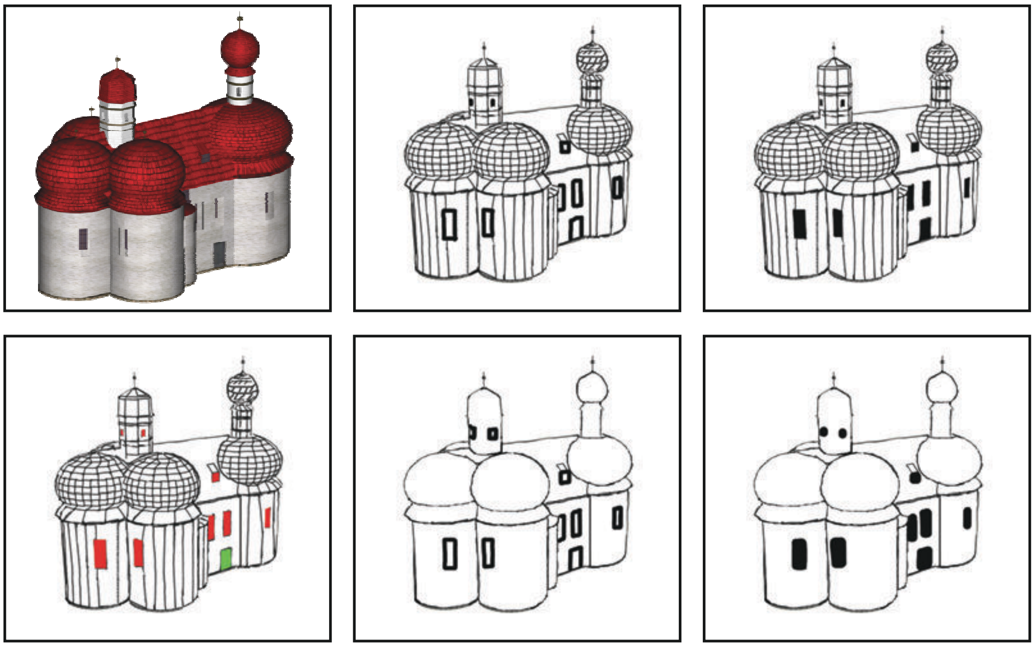

**Figure 9. NPR alternatives of a photorealistic church**

## 6. OUTLOOK

The paper introduces the NPR approach, its potential for the 3D virtual urban environments on mobile displays and feasibility of implementation with the OGC standard CityGML. The first results of our work are presented. According to our plan, in the next stages, a number of design options for two extensive 3D virtual urban environments (Munich and Potsdam) will be implemented with NPR techniques on PDAs. Subsequently, usability test will be conducted with the aim to identify the most cognitive-adequate solution.

## 7. ACKNOWLEDGEMENT

Our work is financed by German Natural Science Foundation (DFG) (ME 1846/4-1, DO 697/5-1). Although we are still in the beginning stage of the on-going joint research project between Technical University of Munich and the Hasso-Plattner-Institut, we wish to share our premature thoughts with researchers and get further inspirations, especially in the aspects of design constraints and usability concerns.

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